[Name of the Document] SPECIFICATION

[Title of the Invention] HIGH CARBON STEEL SHEET HAVING EXCELLENT HARDENABILITY AND TOUGHNESS, AND LOW PLANAR ANISOTROPY, AND PRODUCTION METHOD THEREOF

[Claims]

[Claim 1] A high carbon steel sheet having excellent hardenability and toughness, and low planar anisotropy which contains chemical composition specified by JIS G 4051 (Carbon steels for machine structural use), JIS G 4401 (Carbon tool steels) or JIS G 4802 (Cold-rolled steel strips for springs), wherein

more than 50 carbides having a diameter of 1.5 μm or larger exist in 2500 μm^2,

the ratio of number of carbides having a diameter of 0.6 μm or less with respect to all the carbides is 80 % or more, and

the Δr being a parameter of planar anisotropy of r-value is more than -0.15 to less than 0.15,

herein $\Delta r = (r0 + r90 - 2 \times r45)/4$, and r0, r45, and r90 shows a r-value of the directions of 0°(L), 45°(S) and 90°(C) with respect to the rolling direction respectively.

[Claim 2] A method of producing a high carbon steel sheet having excellent hardenability and toughness, and low planar anisotropy, comprising the steps of:

hot rolling a steel having chemical composition specified by JIS G 4051, JIS G 4401 or JIS G 4802,

coiling the hot rolled steel sheet at 520 to 600 °C,

descaling the coiled steel sheet,

primarily annealing the descaled steel sheet at 640 to 690 °C for 20 hr or longer,

cold rolling the annealed steel sheet at a reduction rate of 50 % or more, and

secondarily annealing the cold rolled steel sheet at 620 to 680 °C.

[Claim 3] A high carbon steel sheet having excellent hardenability and toughness, and low planar anisotropy which contains chemical composition specified by JIS G 4051, JIS G 4401 or JIS G 4802, wherein

more than 50 carbides having a diameter of 1.5 μm or larger exist in 2500 μm^2,

the ratio of number of carbides having a diameter of 0.6 μm or less with respect to all the carbides is 80 % or more, and

the Δmax of r-value is less than 0.2,

herein the Δmax of r-value is a difference between maximum value and minimum value among r0, r45 and r90.

[Claim 4] A method of producing a high carbon steel sheet having excellent hardenability and toughness, and low planar anisotropy, comprising the steps of:

hot rolling a steel having chemical composition specified by JIS G 4051, JIS G 4401 or JIS G 4802,

coiling the hot rolled steel sheet at 520 to 600 °C,

descaling the coiled steel sheet,

primarily annealing the descaled steel sheet at a temperature T1 of 640 to 690 °C for 20 hr or longer,

cold rolling the annealed steel sheet at a reduction rate

of 50 % or more, and

secondarily annealing the cold rolled steel sheet at a temperature T2 of 620 to 680 °C,

wherein the temperature T1 and the temperature T2 satisfy the following formula (1),

$$1024 - 0.6 \times T1 \leqq T2 \leqq 1202 - 0.80 \times T1 \ldots (1).$$

[Claim 5] A method of producing a high carbon steel sheet having excellent hardenability and toughness, and low planar anisotropy, comprising the steps of:

continuously casting into slab a steel containing chemical composition specified by JIS G 4051, JIS G 4401 or JIS G 4802,

rough rolling the slab to sheet bar without reheating the slab or after reheating the slab cooled to a certain temperature,

finish rolling the sheet bar after reheating the sheet bar to Ar3 transformation point or higher, or during reheating the rolled sheet bar to Ar3 transformation point or higher,

coiling the finish rolled steel sheet at 500 to 650 °C,

descaling the coiled steel sheet,

primarily annealing the descaled steel sheet at a temperature T1 of 630 to 700 °C for 20 hr or longer,

cold rolling the annealed steel sheet at a reduction rate of 50 % or higher, and

secondarily annealing the cold rolled steel sheet at a temperature T2 of 620 to 680 °C,

wherein the temperature T1 and the temperature T2 satisfy the following formula (2),

$$1010 - 0.59 \times T1 \leqq T2 \leqq 1210 - 0.80 \times T1 \ldots (2).$$

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to a high carbon steel sheet having excellent hardenability and toughness, and low planar anisotropy of tensile properties which is applied to parts formed into, for example, disk or cylinder with a high dimensional precision and then subjected to heat treatment such as quenching and tempering, and a method of producing the same.

[0002]

[Description of Background Art]

High carbon steel sheets have conventionally been applied to parts for machine structural use such as washers, chains or the like. Such high carbon steel sheets have accordingly been demanded to have good hardenability, and recently not only the good hardenability after quenching treatment but also low temperature - short time of quenching treatment for cost down and high toughness after quenching treatment for safety during services.

[0003]

In addition, since the high carbon steel sheets have poor formability as compared with low carbon steel sheets and large planar anisotropy of mechanical properties caused by production process such as hot rolling, annealing and cold rolling, it has been difficult to apply the high carbon steel sheets to parts as gears which are conventionally produced by casting or forging with a high dimensional precision.

[0004]

Therefore, it has been requested to improve the hardenability and the toughness of the high carbon steel sheets, and to reduce their planar anisotropy of mechanical properties.

[0005]

The following methods have been proposed to meet the requirement.

[0006]

(1) JP-A-5-9588, (the term "JP-A" referred to herein signifies "Unexamined Japanese Patent Publication") (Prior Art 1): hot rolling, cooling down to 20 to 500 °C at a rate of 10 °C/sec or higher so as to form fine pearlites, reheating for a short time, and coiling in order to accelerate spheroidization of carbides for improving the hardenability.

[0007]

(2) JP-A-5-98388 (Prior Art 2): adding Nb and Ti to high carbon steels containing 0.30 to 0.70 % of C so as to form carbonitrides for restraining austenite grain growth and improving the toughness.

[0008]

(3) "Material and Process", vol.1 (1988), p.1729 (Prior Art 3): hot rolling a high carbon steel containing 0.65 % of C, cold rolling (reduction rate: 50 %), batch annealing at 650 °C for 24 hr, subjecting to secondary cold rolling (reduction rate: 65 %), and batch annealing at 680 °C for 24 hr for improving the workability; otherwise adjusting the chemical composition of a high carbon steel containing 0.65 % of C, repeating the rolling

and the annealing as above mentioned so as to graphitize cementites for decreasing the tensile strength, improving the r value and the elongation, and reducing the planar anisotropy of r-value to the same degree as low carbon steel sheets.

[0009]

(4) JP-A-10-152757 (Prior Art 4): adjusting contents of C, Si, Mn, P, Cr, Ni, Mo, V, Ti and Al, decreasing S content below 0.002 wt%, so that 6 μm or less is the average length of sulfide based non metallic inclusions narrowly elongated in the rolling direction, and 80 % or more of all the inclusions are the inclusions whose length in the rolling direction is 4 μm or less, whereby the planar anisotropy of toughness and ductility is made so small that the ratio of toughness and ductility in the rolling direction to those in the orthogonal direction to the rolling direction is 0.9 to 1.0.

[0010]

(5) JP-A-6-271935 (Prior Art 5): hot rolling, at Ar3 transformation point or higher, a steel whose contents of C, Si, Mn, Cr, Mo, Ni, B and Al were specified, cooling at a rate of 30 °C/sec or higher, coiling at 550 to 700 °C, descaling, annealing at 600 to 680 °C, cold rolling at a reduction rate of 40 % or more, further annealing at 600 to 680 °C, and temper rolling so as to reduce the planar shape anisotropy caused by heat treatment such as quenching and tempering.

[0011]

[Problems to be Solved by the Invention]

However, there are following problems in the above

mentioned prior arts.

Prior Art 1: Although reheating for a short time, followed by coiling, a treating time for spheroidizing carbides is very short, and the spheroidization of carbides is insufficient so that the good hardenability might not be probably sometimes provided. Further, for reheating for a short time until coiling after cooling, a rapidly heating apparatus such as an electrically conductive heater is needed, resulting in an increase of production cost.

[0012]

Prior Art 2: Because of adding expensive Nb and Ti in order to restrain the austenite grain growth, the production cost is increased.

[0013]

Prior Art 3: Although the steel sheet of S65C having ferrite and cementite structure shows a high average r-value of around 1.3, the $\Delta r = (r0 + r90 - 2 \times r45)/4$ is -0.47, which is a parameter of planar anisotropy of r-value, herein, r0, r45, and r90 shows a r-value of the directions of 0°(L), 45°(S) and 90°(C) with respect to the rolling direction respectively, and the Δmax of r-value being a difference between the maximum value and the minimum value among r0, r45, and r90 is 1.17. As a result, the planar anisotropy of r-value is large. In addition, two times of cold rolling and annealing cause an increase in production cost.

By graphitizing the cementites, the average r-value is further increased, the Δr decreases to 0.34 and the Δmax of

r-value decreases to 0.85. The planar anisotropy of r-value is still large. In case graphitizing, since a dissolving speed of graphites into austenite phase is slow, the hardenability is remarkably degraded.

[0014]

Prior Art 4: The planar anisotropy of toughness and elongation is considered, but the average r-value and n-value which are important parameters for the workability is not investigated.

[0015]

Prior Art 5: The method for producing a high carbon steel sheet having a good dimensional precision at quenching and tempering is described, but no planar anisotropy is referred to.

[0016]

The present invention has been realized to solve above these problems, and it is an object of the invention to provide a high carbon steel sheet having excellent hardenability and toughness, and low planar anisotropy of tensile properties affecting workability, and a method of producing the same.

[0017]

[Means to Solve the Problems]

The present inventors made a study on the high carbon steel sheet containing carbon 0.2 % or more of carbon and chemical composition specified by JIS G 4051, JIS G 4401 or JIS G4802 to improve the hardenability, the toughness and the planar anisotropy of tensile properties, and found that it was effective to control the coiling temperature after hot rolling, the

temperature of primary annealing, the cold rolling reduction rate, and the temperature of second annealing, or to reheat the sheet bar to Ar3 transformation point or higher before or during finish rolling for improving the structural uniformity in a thickness direction of steel sheet in addition to the control described above, whereby the existing condition of carbides precipitated in steel was optimized. Further, by the above means, the Δr decreased to −0.15 to 0.15 and the Δmax of r-value below 0.2.

[0018]

The present invention has been be accomplished on the base of these findings. The first invention is a high carbon steel sheet having excellent hardenability and toughness, and low planar anisotropy which contains chemical composition specified by JIS G 4051 (Carbon steels for machine structural use), JIS G 4401 (Carbon tool steels) or JIS G 4802 (Cold-rolled steel strips for springs), wherein more than 50 carbides having a diameter of 1.5 μm or larger exist in 2500 μm^2, the ratio of number of carbides having a diameter of 0.6 μm or less with respect to all the carbides is 80 % or more, and the Δr being a parameter of planar anisotropy of r-value is more than −0.15 to less than 0.15, herein Δr = (r0 + r90 − 2 x r45)/4, and r0, r45, and r90 shows a r-value of the directions of 0°(L), 45°(S) and 90°(C) with respect to the rolling direction respectively.

[0019]

The second invention is a method of producing a high carbon steel sheet having excellent hardenability and toughness, and low planar anisotropy, comprising the steps of: hot rolling a

steel having chemical composition specified by JIS G 4051, JIS G 4401 or JIS G 4802, coiling the hot rolled steel sheet at 520 to 600 °C, descaling the coiled steel sheet, primarily annealing the descaled steel sheet at 640 to 690 °C for 20 hr or longer, cold rolling the annealed steel sheet at a reduction rate of 50 % or more, and secondarily annealing the cold rolled steel sheet at 620 to 680 °C.

[0020]

The third invention is a high carbon steel sheet having excellent hardenability and toughness, and low planar anisotropy which contains chemical composition specified by JIS G 4051, JIS G 4401 or JIS G 4802, wherein more than 50 carbides having a diameter of 1.5 μm or larger exist in 2500 μm^2, the ratio of number of carbides having a diameter of 0.6 μm or less with respect to all the carbides is 80 % or more, and the Δmax of r-value is less than 0.2, herein the Δmax of r-value is a difference between maximum value and minimum value among r0, r45 and r90.

[0021]

The forth invention is a method of producing a high carbon steel sheet having excellent hardenability and toughness, and low planar anisotropy, comprising the steps of: hot rolling a steel having chemical composition specified by JIS G 4051, JIS G 4401 or JIS G 4802, coiling the hot rolled steel sheet at 520 to 600 °C, descaling the coiled steel sheet, primarily annealing the descaled steel sheet at a temperature T1 of 640 to 690 °C for 20 hr or longer, cold rolling the annealed steel sheet at a reduction rate of 50 % or more, and secondarily annealing the

cold rolled steel sheet at a temperature T2 of 620 to 680 °C, wherein the temperature T1 and the temperature T2 satisfy the following formula (1),

$$1024 - 0.6 \times T1 \leqq T2 \leqq 1202 - 0.80 \times T1 \quad \ldots \quad (1).$$

[0022]

The fifth invention is a method of producing a high carbon steel sheet having excellent hardenability and toughness, and low planar anisotropy, comprising the steps of: continuously casting into slab a steel containing chemical composition specified by JIS G 4051, JIS G 4401 or JIS G 4802, rough rolling the slab to sheet bar without reheating the slab or after reheating the slab cooled to a certain temperature, finish rolling the sheet bar after reheating the sheet bar to Ar3 transformation point or higher, or during reheating the rolled sheet bar to Ar3 transformation point or higher, coiling the finish rolled steel sheet at 500 to 650 °C, descaling the coiled steel sheet, primarily annealing the descaled steel sheet at a temperature T1 of 630 to 700 °C for 20 hr or longer, cold rolling the annealed steel sheet at a reduction rate of 50 % or higher, and secondarily annealing the cold rolled steel sheet at a temperature T2 of 620 to 680 °C, wherein the temperature T1 and the temperature T2 satisfy the following formula (2),

$$1010 - 0.59 \times T1 \leqq T2 \leqq 1210 - 0.80 \times T1 \quad \ldots \quad (2).$$

[0023]

The planar anisotropy means the maximum difference between tensile properties of the directions 0°(L), 45°(S) and 90°(C) with respect to the rolling direction.

[0024]

[Detailed Description of the Invention]

The invention will be explained in detail as follows.

The first invention is a high carbon steel sheet having excellent hardenability and toughness, and low planar anisotropy which contains 0.2 % or more of carbon and chemical composition specified by JIS G 4051 (Carbon steels for machine structural use), JIS G 4401 (Carbon tool steels) or JIS G 4802 (Cold-rolled steel strips for springs), wherein more than 50 carbides having a diameter of 1.5 μm or larger exist in 2500 μm^2, the ratio of number of carbides having a diameter of 0.6 μm or less with respect to all the carbides is 80 % or more, and the Δr being a parameter of planar anisotropy of r-value is more than -0.15 to less than 0.15, herein $\Delta r = (r0 + r90 - 2 \times r45)/4$, and r0, r45, and r90 shows a r-value of the directions of 0°(L), 45°(S) and 90°(C) with respect to the rolling direction respectively.

Next, the reason of specifying the above features will be given.

[0025]

(1) Number of carbides having a diameter of 1.5 μm or larger in 2500 μm^2: more than 50, and ratio of number of carbides having a diameter of 0.6 μm or less with respect to all the carbides: 80 % or more

Existing condition of carbides has a strong influence on the hardenability and the toughness after quenching treatment in which low temperature and short time heating is conducted. The effect of the carbide condition was first studied.

[0026]

By making a steel having, by wt%, C: 0.36 %, Si: 0.20 %, Mn: 0.75 %, P: 0.011 %, S: 0.002 % and Al: 0.020 %, hot rolling at a finishing temperature of 850 °C, coiling at a coiling temperature of 560 °C, pickling, primarily annealing at 640 to 690 °C for 40 hr, cold rolling at a reduction rate of 60 %, and secondarily annealing at 610 to 690 °C for 40 hr, steel sheets were produced. Cutting out samples of 50 x 100 mm from the produced steel sheets, and heating at 820 °C for 10 sec, followed by quenching into oil at around 20 °C, the average hardness was measured over 10 portions by Rockwell C Scale (HRc) to evaluate the hardenability. If the average HRc is 50 or more, it may be judged that the good hardenability is provided.

[0027]

Fig. 1 shows the relationship between carbide diameter and hardness in which more than 80 % of carbides in 2500 μm^2 have this diameter or less. When this carbide diameter is 0.6 μm or less, the hardness (HRc) is 50 or higher. That is, when 80 % or more is the ratio of number of carbides having diameters ≦ 0.6 μm, the carbides are rapidly dissolved into the austenite phase, so that the hardenability is improved. However, if all the carbides have diameters ≦ 0.6, they are dissolved into the austenite phase at a short time heating and then the austenite grain is extremely coarsened.

[0028]

Fig. 2 shows the relationship between number of carbides having a diameter of 1.5 μm or larger in 2500 μm^2 and austenite

grain size. The decrease in number of carbides coarsens the austenite grain size. It is remarkable particularly when the number of carbides is below 50. The smaller is the austenite grain size, the higher is the toughness. Therefore, it is necessary to precipitate carbides having a diameter of 1.5 μm or larger, but the austenite grain size is not small unless at least 50 or more of the carbides exist in 2500 μm^2.

[0029]

The measurement of carbide diameter and number of carbides is not limited to a special method. However, it is preferable to observe carbides using a scanning electron microscope at 1500 to 5000 magnifications after polishing the cross section in a thickness direction of steel sheet sample and etching it, to take the photos, and to measure the carbide diameter and the number of carbides on the photos. The carbide diameter should be measured by averaging the diameters of the carbides observable on the photos. The measurement of the carbide diameter and the number of carbides should be conducted in an observation field area of 2500 μm^2 or more, because if the observation field area is smaller than 2500 μm^2, the number of observable carbides is too small, and therefore the diameter and the number of carbides could not be measured precisely. As to the upper limit of the observation field area, it is sufficient that the above condition of carbides is obtained at around 60 % of cross section area in a thickness direction. The etching agent should preferably be a picral.

[0030]

(2) Δr: more than -0.15 to less than 0.15

The high carbon steel sheet having a very low Δr of more than -0.15 to less than 0.15 can be applied to gear parts produced conventionally by casting or forging which need a high dimensional precision.

[0031]

The above mentioned high carbon steel sheet can be produced by the method of the second invention comprising the steps of: hot rolling a steel having chemical composition specified by JIS G 4051, JIS G 4401 or JIS G 4802, coiling the hot rolled steel sheet at 520 to 600 °C, descaling the coiled steel sheet, primarily annealing the descaled steel sheet at 640 to 690 °C for 20 hr or longer, cold rolling the annealed steel sheet at a reduction rate of 50 % or more, and secondarily annealing the cold rolled steel sheet at 620 to 680 °C. The details will be explained as follows.

[0032]

(1) Coiling temperature: 520 to 600 ℃

Since the coiling temperature lower than 520 °C makes pearlite structure very fine, carbides after the primary annealing are considerably fine, so that carbides having a diameter of 1.5 μm or larger cannot be produced after the secondary annealing. In contrast, exceeding 600 °C, coarse pearlite structure is generated, so that carbides having a diameter of 0.6 μm or less cannot be produced after the secondary annealing. Accordingly, the coiling temperature is defined to be 520 to 600 °C.

[0033]

(2) Primary annealing: 640 to 690 ℃ for 20 hr or longer

The primary annealing is carried out on the coiled and descaled steel sheet in order to spheroidize carbides. If the primary annealing temperature is higher than 690 °C, carbides are too much spheroidized, so that carbides having a diameter of 0.6 μm or less cannot be produced after the secondary annealing. On the other hand, being lower than 640 °C, the spheroidization of carbides is difficult, so that carbides having a diameter of 1.5 μm or larger cannot be produced after the secondary annealing. Accordingly, the primary annealing temperature is defined to be 640 to 690 °C. The annealing time should be 20 hr or longer for uniformly spheroidizing carbides.

[0034]

(3) Cold reduction rate: 50 % or more

In general, the higher the cold reduction rate, the smaller the Δr, and for decreasing the Δr sufficiently, the cold reduction rate of at least 50 % is necessary. The upper limit is not always defined, but the cold reduction rate of 80 % or less is preferable because the cold reduction rate of above 80 % makes it difficult to handle a steel sheet.

[0035]

(4) Secondary annealing: 620 to 680 ℃

The cold rolled steel sheet is annealed for recrystallization. If the secondary annealing temperature exceeds 680 °C, carbides are greatly coarsened, recrystallized grains grow markedly, the r-value of orthogonal direction to the

rolling direction (C) becomes much higher than those of other directions (L or S), and the Δr increases. On the other hand, being lower than 620 °C, carbides become fine, and recrystallized grains do not grow sufficiently, so that the workability decreases. Thus, the secondary annealing temperature is defined to be 620 to 680 °C. For the secondary annealing, either a continuous annealing or a box annealing will do.

[0036]

The third invention is a high carbon steel sheet having 0.2 % or more of carbon and chemical composition specified by JIS G 4051 (Carbon steels for machine structural use), JIS G 4401 (Carbon tool steels) or JIS G 4802 (Cold-rolled steel strips for springs), wherein more than 50 carbides having a diameter of 1.5 µm or larger exist in 2500 µm^2, the ratio of number of carbides having a diameter of 0.6 µm or less with respect to all the carbides is 80 % or more, and the Δmax of r-value is less than 0.2. Here, the Δmax of r-value is a maximum difference between the maximum r-value and minimum r-value among r0, r45 and r90. The details will be explained as follows.

[0037]

(1) Number of carbides having a diameter of 1.5 µm or larger in 2500 µm^2: more than 50, and ratio of number of carbides having a diameter of 0.6 µm or less with respect to all the carbides: 80 % or more

The reason for specifying the existing condition of carbides like this is, as described above in case of the first invention, that the austenite grain becomes fine by precipitating

more than 50 carbides having a diameter of 1.5 μm or larger in 2500 μm^2, improving the toughness, and the good hardenability is obtained by controlling the ratio of number of carbides having a diameter of 0.6 μm or less with respect to all the carbides to 80 % or more.

[0038]

(2) Δmax of r-value: less than 0.2

The high carbon steel sheet having a very low Δmax of r-value of less than 0.2 can be applied to gear parts produced conventionally by casting or forging which need a high dimensional precision.

[0039]

The above mentioned high carbon steel sheet can be produced by the following method 1 or 2.

[0040]

The method 1 comprises the steps of: hot rolling a steel having chemical composition specified by JIS G 4051, JIS G 4401 or JIS G 4802, coiling the hot rolled steel sheet at 520 to 600 °C, descaling the coiled steel sheet, primarily annealing the descaled steel sheet at a temperature T1 of 640 to 690 °C for 20 hr or longer, cold rolling the annealed steel sheet at a reduction rate of 50 % or more, and secondarily annealing the cold rolled steel sheet at a temperature T2 of 620 to 680 °C, wherein the temperature T1 and the temperature T2 satisfy the following formula (1).

$$1024 - 0.6 \times T1 \leqq T2 \leqq 1202 - 0.80 \times T1 \quad \ldots \quad (1)$$

[0041]

(1) Coiling temperature: 520 to 600 ℃

As described in the method of the second invention, the coiling temperature lower than 520 °C cannot produce carbides having a diameter of 1.5 µm or larger after the secondary annealing. In contrast, exceeding 600 °C, carbides having a diameter of 0.6 µm or less cannot be produced after the secondary annealing. Accordingly, the coiling temperature is defined to be 520 to 600 °C.

[0042]

(2) Primary annealing: 640 to 690 ℃ for 20 hr or longer

As described in the method of the second invention, the primary annealing is carried out on the coiled and descaled steel sheet in order to spheroidize carbides. If the primary annealing temperature is higher than 690 °C, carbides having a diameter of 0.6 µm or less cannot be produced after the secondary annealing. On the other hand, being lower than 640 °C, carbides having a diameter of 1.5 µm or larger cannot be produced after the secondary annealing. Accordingly, the primary annealing temperature is defined to be 640 to 690 °C. The annealing time should be 20 hr or longer for uniformly spheroidizing carbides.

[0043]

(3) Cold reduction rate: 50 % or more

As described in the method of the second invention, for decreasing the Δr sufficiently, the cold reduction rate of at least 50 % is necessary. The upper limit is not always defined, but the cold reduction rate of 80 % or less is preferable from a view point of handling a steel sheet.

[0044]

(4) Secondary annealing: $1024 - 0.6 \times T1 \leqq T2 \leqq 1202 - 0.80 \times T1$, and $620\ ℃ \leqq T2 \leqq 680\ ℃$

The secondary annealing condition should be controlled with the primary annealing condition to decrease the Δmax of r-value. Then, the effect of the primary annealing condition and the second annealing condition on the Δmax of r-value was investigated. The details will be described as follows.

[0045]

By making a steel of, by wt%, C: 0.36 %, Si: 0.20 %, Mn: 0.75 %, P: 0.011 %, S: 0.002 % and Al: 0.020 %, hot rolling at a finishing temperature of 850 °C and coiling at a coiling temperature of 560 °C, pickling, primarily annealing at 640 to 690 °C for 40 hr , cold rolling at a reduction rate of 60 %, and secondarily annealing at 610 to 690 °C for 40 hr, steel sheets were produced, and the Δmax of r-value was measured by a tensile test. Fig. 3 shows the effect of primary annealing temperature and secondary annealing temperature on the Δmax of r-value. As seen in Fig. 3, if the secondary annealing temperature T2 is $(1024 - 0.6 \times T1)$ to $(1202 - 0.80 \times T1)$, the Δmax of r-value is less than 0.2, and the planar anisotropy is small. Accordingly, the relation of $1024 - 0.6 \times T1 \leqq T2 \leqq 1202 - 0.80 \times T1$ is necessary. The Δmax of r-value is a maximum difference between the maximum r-value and minimum r-value among r0, r45 and r90.

[0046]

The secondary annealing temperature has a strong influence on the carbide diameter and the carbide dispersion. If the

secondary annealing temperature exceeds 680 °C, carbides are coarsened, and carbides having a diameter of 0.6 μm or less cannot be produced. On the other hand, being lower than 620 °C, carbides having a diameter of 1.5 μm or larger cannot be produced. Thus, the secondary annealing temperature T2 is defined to be 620 to 680 °C. For the secondary annealing, either a continuous annealing or a box annealing will do.

[0047]

Next, the method 2 will be explained.

The method 2 comprises the steps of: continuously casting into slab a steel containing chemical composition specified by JIS G 4051, JIS G 4401 or JIS G 4802, rough rolling the slab to sheet bar without reheating the slab or after reheating the slab cooled to a certain temperature, finish rolling the sheet bar after reheating the sheet bar to Ar3 transformation point or higher, or during reheating the rolled sheet bar to Ar3 transformation point or higher, coiling the finish rolled steel sheet at 500 to 650 °C, descaling the coiled steel sheet, primarily annealing the descaled steel sheet at a temperature T1 of 630 to 700 °C for 20 hr or longer, cold rolling the annealed steel sheet at a reduction rate of 50 % or higher, and secondarily annealing the cold rolled steel sheet at a temperature T2 of 620 to 680 °C, wherein the temperature T1 and the temperature T2 satisfy the following formula (2),

$$1010 - 0.59 \times T1 \leqq T2 \leqq 1210 - 0.80 \times T1 \quad \ldots (2).$$

Detailed explanation will be made explained as follows.

[0048]

(1) Reheating the sheet bar

By reheating the sheet bar, crystal grains are uniformed in a thickness direction of steel sheet during rolling, the dispersion of carbides after the secondary annealing is small, and the planar anisotropy of r-value becomes smaller. Concretely, the finish rolling of the sheet bar after reheating the sheet bar to Ar3 transformation point or higher, or during reheating the rolled sheet bar to Ar3 transformation point or higher is conducted. The reheating temperature should be Ar3 transformation point or higher to uniform the austenite grain and the structure. The reheating time should be at least 3 seconds.

[0049]

(2) Coiling temperature: 520 to 600 ℃

As described in the method 1, the coiling temperature lower than 520 °C cannot produce carbides having a diameter of 1.5 μm or larger after the secondary annealing. In contrast, exceeding 600 °C, carbides having a diameter of 0.6 μm or less cannot be produced after the secondary annealing. Accordingly, the coiling temperature is defined to be 520 to 600 °C.

[0050]

(2) Primary annealing: 640 to 690 ℃ for 20 hr or longer

As described in the method 1, the primary annealing is carried out on the coiled and descaled steel sheet in order to spheroidize carbides. If the primary annealing temperature is higher than 690 °C, carbides having a diameter of 0.6 μm or less cannot be produced after the secondary annealing. On the other

hand, being lower than 640 °C, carbides having a diameter of 1.5 μm or larger cannot be produced after the secondary annealing. Accordingly, the primary annealing temperature is defined to be 640 to 690 °C. The annealing time should be 20 hr or longer for uniformly spheroidizing carbides.

[0051]

(4) Cold reduction rate: 50 % or more

As described in the method 1, for decreasing the Δr sufficiently, the cold reduction rate of at least 50 % is necessary. The cold reduction rate of 80 % or less is preferable from a view point of handling a steel sheet.

[0052]

(5) Secondary annealing: $1010 - 0.59 \times T1 \leqq T2 \leqq 1210 - 0.80 \times T1$, and $620\ ℃ \leqq T2 \leqq 680\ ℃$

As described in the method 1, the secondary annealing condition should be controlled with the primary annealing condition to decrease the Δmax of r-value. Then, the effect of the primary annealing condition and the second annealing condition on the Δmax of r-value was investigated. The results will be described as follows.

[0053]

By making a slab of, by wt%, C: 0.36 %, Si: 0.20 %, Mn: 0.75 %, P: 0.011 %, S: 0.002 % and Al: 0.020 %, rough rolling, reheating the sheet bar at 1010 °C for 15 sec by an induction heater, finish rolling at 850 °C, coiling at 560 °C, pickling, primarily annealing at 640 to 700 °C for 40 hr, cold rolling at a reduction rate of 60 %, and secondarily annealing at 610 to

690 °C for 40 hr, steel sheets were produced. Measurements were made on the (222) integrated reflective intensity in the thickness directions (surface, 1/4 thickness and 1/2 thickness) by a X-ray diffraction method. As shown in Table 1, by reheating the sheet bar using an induction heater, the Δmax of (222) intensity being a maximum difference between the maximum value and the minimum value of (222) integrated reflective intensities in the thickness directions becomes small, and therefore the structure is more uniform in the thickness direction. Fig. 4 shows the effect of primary annealing temperature and secondary annealing temperature on the Δmax of r-value. In the method 1, as shown in Fig. 3, the Δmax of r-value is less than 0.2 when the secondary annealing temperature T2 is (1024 - 0.6 x T1) to (1202 - 0.80 x T1). On the other hand, by reheating the sheet bar using an induction heater in the method 2, the Δmax of r-value is further reduced to less than 0.15 in a wider range of T2, that is, $1010 - 0.59 \times T1 \leqq T2 \leqq 1210 - 0.80 \times T1$.

[0054]

Table 1

Reheating of sheet bar (℃xsec)	Primary annealing (℃xhr)	Secondary annealing (℃xhr)	Integrated reflective intensity (222)			
			Surface	1/4 thickness	1/2 thickness	Δmax
1010 x 15	640 x 40	610 x 40	2.81	2.95	2.89	0.14
1010 x 15	640 x 40	650 x 40	2.82	2.88	2.95	0.13
1010 x 15	640 x 40	690 x 40	2.90	2.91	3.02	0.12
1010 x 15	680 x 40	610 x 40	2.37	2.35	2.46	0.11
1010 x 15	680 x 40	650 x 40	2.40	2.36	2.47	0.11
1010 x 15	680 x 40	690 x 40	2.29	2.34	2.39	0.10
-	640 x 40	610 x 40	2.70	3.01	2.90	0.31
-	640 x 40	650 x 40	2.75	2.87	2.99	0.24
-	640 x 40	690 x 40	2.81	2.90	3.05	0.24
-	680 x 40	610 x 40	2.34	2.27	2.50	0.23
-	680 x 40	650 x 40	2.39	2.23	2.51	0.28
-	680 x 40	690 x 40	2.25	2.37	2.45	0.20

[0055]

As described in the method 1, the secondary annealing temperature T2 is defined to be 620 to 680 °C to produce some carbides having a diameter of 0.6 μm or less and other carbides having a diameter of 1.5 μm or larger. For the secondary annealing, either a continuous annealing or a box annealing will do.

[0056]

To produce the high carbon steel sheet of the present invention, a continuously cast slab may be hot rolled after being reheated or directly hot rolled after being cast. The sheet bar may be reheated by a bar heater. The bar heating is effective

in a continuous hot rolling process using a coil box. In this process, the sheet bar may be also reheated before or after the coil box, or before and after a welding machine. For improving the sliding property, the high carbon steel sheet of the present invention may be galvanized through an electro-galvanizing process or a hot dip Zn plating process, followed by a phosphating treatment.

[0057]

[Example]

(Example 1)

This example relates to the high carbon steel sheet of the first invention.

By making a slab containing the chemical composition specified by S35C of JIS G 4051 (by wt%, C: 0.35 %, Si: 0.20 %, Mn: 0.76 %, P: 0.016 %, S: 0.003 % and Al: 0.026 %) through a continuous casting process, reheating to 1100 °C, hot rolling, coiling, primarily annealing, cold rolling, secondarily annealing, under the conditions shown in Table 2, and temper rolling at a reduction rate of 1.5 %, steel sheets of 1.0 mm thickness were produced. Herein, the steel sheet H is a conventional high carbon steel sheet.

[0058]

Table 2

Steel sheet	Coiling temperature (℃)	Primary annealing (℃xhr)	Cold reduction rate (%)	Secondary annealing (℃xhr)	Number of carbides larger than 1.5 μm	Ratio of carbides smaller than 0.6 μm (%)	Remark
A	580	650 x 40	70	680 x 40	89	84	Present invention
B	560	640 x 20	60	660 x 40	84	87	Present invention
C	540	660 x 20	65	640 x 40	81	93	Present invention
D	500	640 x 40	60	660 x 40	64	96	Comparative example
E	560	710 x 40	65	660 x 40	103	58	Comparative example
F	540	660 x 20	40	680 x 40	86	84	Comparative example
G	550	640 x 20	60	720 x 40	98	61	Comparative example
H	620	-	50	690 x 40	74	70	Comparative example

[0059]

Then, carbide diameter, carbide dispersion, tensile properties, hardenability and austenite grain size were measured as follows. The results are shown in Table 3.

[0060]

(a) Carbide diameter and carbide dispersion

The measurement of the diameter and the number of carbide was conducted in an observation field area of 2500 μm^2 on the photos taken by a scanning electron microscope after polishing the cross section in a thickness direction of steel sheet sample and etching it.

[0061]

(b) Tensile properties

JIS No.5 test pieces were sampled from the directions of 0°(L), 45°(S) and 90°(C) with respect to the rolling direction, and subjected to the tensile test at a tension speed of 10 mm/min so as to measure the tensile properties in each direction and the planar anisotropy. The Δmax of yield strength, tensile strength and elongation shown in Table 3 is a difference between the maximum value and the minimum value of each tensile property. The Δr in Table 3 was calculated by the equation $\Delta r = (r0 + r90 - 2 \times r45)/4$, herein, r0, r45, and r90 shows a r-value of the directions of 0°(L), 45°(S) and 90°(C) with respect to the rolling direction respectively.

[0062]

(c) Hardenability

Cutting out samples of 50 x 100 mm from the produced steel

sheets, and heating at 820 °C for 10 sec, followed by quenching into oil at around 20 °C, the average hardness was measured over 10 portions by Rockwell C Scale (HRc) to evaluate the hardenability. If the average HRc is 50 or more, it may be judged that the good hardenability is provided.

[0063]

(d) Austenite grain size

The cross section in a thickness direction of the quenched test piece was polished, etched, and observed by an optical microscope. The austenite grain size number was measured following JIS G 0551.

[0064]

Table 3

Steel sheet	Mechanical properties before quenching																Hardness after quenching (HRc)	Austetine Grain size (size No.)	Remark
	Yield strength (MPa)				Tensile strength (MPa)				Total elongation (%)				r-value						
	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δr			
A	395	391	393	4	506	502	507	5	35.7	36.4	35.9	0.7	1.06	0.97	1.04	0.04	52	11.6	Present invention
B	405	404	411	7	504	498	507	9	35.8	36.8	36.2	1.0	1.12	0.98	1.23	0.10	54	11.3	Present invention
C	409	406	414	8	509	505	513	8	35.2	36.4	35.3	1.2	0.98	1.19	1.05	-0.09	56	10.7	Present invention
D	369	362	370	8	499	496	503	9	30.1	29.3	31.0	1.7	1.16	0.92	1.33	0.16	57	8.6	Comparative example
E	370	379	375	9	480	484	481	4	36.9	38.0	36.4	0.9	1.15	0.96	1.47	0.18	44	12.2	Comparative example
F	374	377	385	11	474	480	488	14	35.7	34.6	36.3	1.7	1.25	0.96	1.46	0.20	53	11.2	Comparative example
G	372	376	379	7	496	493	498	5	38.0	37.7	37.7	0.3	1.14	0.94	1.64	0.23	40	12.1	Comparative example
H	317	334	320	17	501	516	510	15	38.5	34.6	35.5	1.9	1.12	0.92	1.35	0.16	49	11.6	Comparative example

[0065]

As shown in Table 3, since the inventive steel sheets A-C have diameters and numbers of carbides within the range of the present invention, the HRc after quenching of these steel sheets is above 50 and the good hardenability is obtained. And the austenite grain size of these steel sheets is small, and therefore the excellent toughness is obtained. In addition, since the Δ max of yield strength and tensile strength is 10 MPa or lower, the Δmax of the total elongation is 1.5 % or lower, and the Δ r is more than -0.15 to less than 0.15, the planar anisotropy of tensile properties is very small.

[0066]

In contrast, the comparative steel sheets D-H have a large Δmax of tensile properties or a large Δr. The steel sheet D of too low coiling temperature has a large Δmax of elongation of 1.7, a large Δr of 0.16, and poor toughness due to the coarse austenite grain caused by the small number of carbides having a diameter of 1.5 μm or larger. The steel sheet E of too high primary annealing temperature has a large Δr of 0.18 and poor hardenability due to the small number of fine carbides. The steel sheet F of too low cold reduction rate of 40 % has a large Δ max of yield strength of 11 MPa, a large Δmax of tensile strength of 14 MPa, a large Δmax of elongation of 1.7 %, and a large Δ r of 0.20. The steel sheet G of too high secondary annealing temperature has a low HRc due to the large number of coarse carbides and a large Δr of 0.23. The conventional steel sheet H has a large Δmax of yield strength of 17 MPa, a large Δmax

of tensile strength of 15 MPa, a large Δmax of elongation of 1.9 %, and a large Δr of 0.16.

(Example 2)

This example relates to the method 1 for producing the high carbon steel sheet of the third invention.

By making a slab containing the chemical composition specified by S35C of JIS G 4051 (by wt%, C: 0.36 %, Si: 0.20 %, Mn: 0.75 %, P: 0.011 %, S: 0.002 % and Al: 0.020 %) through a continuous casting process, reheating to 1100 °C, hot rolling, coiling, primarily annealing, cold rolling, secondarily annealing, under the conditions shown in Table 4, and temper rolling at a reduction rate of 1.5 %, 19 steel sheets of 2.5 mm thickness were produced.

[0067]

Table 4

Steel sheet	Coiling temperature (℃)	Primary annealing (℃xhr)	Cold reduction rate (%)	Secondary annealing (℃xhr)	Secondary annealing range by the formula (1)	Number of carbides larger than 1.5 μm	Ratio of carbides smaller than 0.6 μm (%)	Remark
1	580	640 x 40	70	680 x 40	640 - 680	56	85	Present invention
2	530	640 x 20	60	680 x 40	640 - 680	52	87	Present invention
3	595	640 x 40	60	680 x 20	640 - 680	64	81	Present invention
4	580	660 x 40	60	660 x 40	628 - 674	61	83	Present invention
5	580	680 x 20	60	640 x 40	620 - 658	63	82	Present invention
6	580	640 x 40	50	660 x 40	640 - 680	56	85	Present invention
7	580	640 x 40	70	640 x 40	640 - 680	54	86	Present invention
8	510	640 x 20	60	680 x 40	640 - 680	30	92	Comparative example
9	610	640 x 20	60	680 x 20	640 - 680	68	61	Comparative example
10	580	620 x 40	60	680 x 40	-	32	90	Comparative example
11	580	720 x 40	60	680 x 40	-	68	65	Comparative example
12	580	640 x 15	70	680 x 40	640 - 680	54	86	Comparative example
13	580	640 x 40	30	680 x 40	640 - 680	58	84	Comparative example
14	580	660 x 20	60	620 x 40	628 - 674	60	84	Comparative example
15	580	640 x 20	60	700 x 40	640 - 680	66	73	Comparative example
16	580	640 x 40	60	690 x 40	640 - 680	67	70	Comparative example
17	580	690 x 40	60	615 x 40	620 - 650	33	88	Comparative example
18	520	640 x 20	60	640 x 20	640 - 680	45	88	Comparative example
19	620	-	50	690 x 40	-	51	67	Comparative example

[0068]

Carbide diameter, carbide dispersion, tensile properties, hardenability and austenite grain size were measured in the same way as shown in the Example 1,. The results are shown in Table 5. Herein, the steel sheet 19 is a conventional high carbon steel sheet.

[0069]

Table 5

Steel sheet	Mechanical properties before quenching																Hardness after quenching (HRc)	Austetine grain size (size No.)	Remark
	Yield strength (MPa)				Tensile strength (MPa)				Total elongation (%)				r-value						
	L	S	C	Δ max	L	S	C	Δ max	L	S	C	Δ max	L	S	C	Δ max			
1	398	394	402	8	506	508	513	5	38.2	37.4	37.0	1.2	1.07	0.99	1.00	0.08	54	11.1	Present invention
2	410	407	412	5	513	512	516	4	36.8	38.0	36.8	1.2	1.02	1.01	1.11	0.10	56	10.9	Present invention
3	350	348	351	3	470	474	472	2	36.3	36.8	36.2	0.6	1.01	1.01	1.09	0.08	51	11.6	Present invention
4	395	398	404	9	507	506	509	3	36.6	37.5	37.3	0.9	1.09	0.99	1.01	0.10	52	11.5	Present invention
5	392	397	400	8	502	503	501	2	37.9	38.2	38.0	0.3	0.95	1.13	1.00	0.18	51	11.5	Present invention
6	401	398	407	9	509	509	512	3	37.5	37.9	38.5	1.0	0.94	1.07	1.02	0.13	53	11.3	Present invention
7	404	401	410	9	510	509	512	3	35.3	36.7	36.6	1.4	1.03	1.18	1.01	0.17	55	11.0	Present invention
8	374	367	374	7	507	505	508	3	29.9	28.4	31.3	2.9	1.17	1.01	1.43	0.42	58	8.3	Comparative example
9	371	386	380	15	482	491	485	9	27.1	25.0	26.7	2.1	1.14	0.93	1.31	0.38	40	12.0	Comparative example
10	395	396	399	4	512	512	515	3	27.0	25.4	28.2	2.8	1.27	0.98	1.28	0.30	58	8.9	Comparative example
11	372	384	380	12	484	489	485	5	37.7	36.9	37.3	0.8	1.24	1.00	1.34	0.34	42	12.0	Comparative example
12	390	384	377	13	490	500	498	10	29.0	24.9	29.4	4.5	1.19	0.94	1.29	0.35	56	10.9	Comparative example
13	372	383	390	18	480	486	493	13	35.5	33.7	36.5	2.8	1.02	0.96	1.48	0.52	53	11.3	Comparative example
14	404	401	410	9	510	508	513	5	35.1	37.0	36.7	1.9	1.01	1.28	0.94	0.34	52	11.4	Comparative example
15	385	386	376	10	503	501	506	5	37.5	36.8	36.4	1.1	1.28	1.00	1.31	0.31	45	11.8	Comparative example
16	388	389	378	11	504	501	507	6	37.3	38.5	38.0	1.3	1.18	0.98	1.36	0.38	43	11.9	Comparative example
17	410	408	417	11	513	510	515	5	35.3	36.7	36.5	1.4	1.02	1.26	0.92	0.34	56	9.9	Comparative example
18	412	406	415	9	514	511	519	8	35.1	36.5	36.3	1.4	0.97	1.22	0.88	0.34	57	9.4	Comparative example
19	322	335	322	13	510	519	514	9	36.1	34.1	35.9	2.0	1.12	0.93	1.36	0.43	43	12.0	Comparative example

[0070]

As shown in Table 5, since the inventive steel sheets 1-7 have diameters and numbers of carbides within the range of the present invention, the HRc after quenching of these steel sheets is above 50 and the good hardenability is obtained. And the austenite grain size of these steel sheets is small, and therefore the excellent toughness is obtained. In addition, since the Δmax of yield strength and tensile strength is 10 MPa or lower, the Δmax of the total elongation is 1.5 % or lower, and the Δmax of r-value is less than 0.2, the planar anisotropy of tensile properties is very small.

[0071]

In contrast, the comparative steel sheets have a large Δmax of tensile properties, or poor hardenability or toughness. The steel sheet 11 of too high primary annealing temperature has a large Δmax of r-value of 0.30. The steel sheet 13 of too low cold reduction rate of 30 % has a large Δmax of yield strength of 18 MPa, a large Δmax of tensile strength of 13 MPa, and a large Δmax of r-value of 0.38. The steel sheet 16 of too high secondary annealing temperature has a low HRc of 43 due to the insufficient dissolution of carbides. The steel sheet 17 of too low secondary annealing temperature has poor toughness due to the coarse austenite grain caused by the large number of carbides having a diameter of 0.6 μm or less. The conventional steel sheet 19 has a large Δmax of r-value of 0.42.

[0072]

(Example 3)

This example relates to the method 1 for producing the high carbon steel sheet of the third invention, too.

By making a slab containing the chemical composition specified by S65C-CSP of JIS G 4802 (by wt%, C: 0.65 %, Si: 0.19 %, Mn: 0.73 %, P: 0.011 %, S: 0.002 % and Al: 0.020 %) through a continuous casting process, reheating to 1100 °C, hot rolling, coiling, primarily annealing, cold rolling, secondarily annealing, under the conditions shown in Table 6, and temper rolling at a reduction rate of 1.5 %, 19 steel sheets of 2.5 mm thickness were produced.

[0073]

Table 6

Steel sheet	Coiling temperature (℃)	Primary annealing (℃xhr)	Cold reduction rate (%)	Secondary annealing (℃xhr)	Secondary annealing range by the formula (1)	Number of carbides larger than 1.5 μm	Ratio of carbides smaller than 0.6 μm (%)	Remark
20	560	640 x 40	70	680 x 40	640 – 680	86	86	Present invention
21	530	640 x 20	60	680 x 40	640 – 680	82	88	Present invention
22	595	640 x 40	60	680 x 20	640 – 680	94	82	Present invention
23	560	660 x 40	60	660 x 40	628 – 674	90	83	Present invention
24	560	680 x 20	60	640 x 40	620 – 658	92	83	Present invention
25	560	640 x 40	50	660 x 40	640 – 680	87	85	Present invention
26	560	640 x 40	70	640 x 40	640 – 680	83	86	Present invention
27	510	640 x 20	60	680 x 40	640 – 680	44	93	Comparative example
28	610	640 x 20	60	680 x 20	640 – 680	101	62	Comparative example
29	560	620 x 40	60	680 x 40	-	47	91	Comparative example
30	560	720 x 40	60	680 x 40	-	100	64	Comparative example
31	560	640 x 15	70	680 x 40	640 – 680	83	87	Comparative example
32	560	640 x 40	30	680 x 40	640 – 680	88	85	Comparative example
33	560	660 x 20	60	620 x 40	630 – 674	89	84	Comparative example
34	560	640 x 20	60	700 x 40	640 – 680	98	72	Comparative example
35	560	640 x 40	60	690 x 40	640 – 680	99	70	Comparative example
36	560	690 x 40	60	615 x 40	620 – 650	49	89	Comparative example
37	600	690 x 40	50	650 x 40	620 – 650	96	77	Comparative example
38	620	-	50	690 x 40	-	100	65	Comparative example

[0074]

Carbide diameter, carbide dispersion, tensile properties, hardenability and austenite grain size were measured in the same way as shown in the Example 1,. The results are shown in Table 7. Herein, the steel sheet 38 is a conventional high carbon steel sheet.

[0075]

Table 7

Steel sheet	Mechanical properties before quenching																Hardness after quenching (HRc)	Austetine Grain size (size No.)	Remark
	Yield strength (MPa)				Tensile strength (MPa)				Total elongation (%)				r-value						
	L	S	C	Δ max	L	S	C	Δ max	L	S	C	Δ max	L	S	C	Δ max			
20	412	406	413	7	515	518	523	8	34.2	35.7	35.2	1.5	1.04	0.96	0.97	0.08	63	11.2	Present invention
21	422	419	427	8	524	521	526	5	35.1	36.0	34.6	1.4	0.98	1.00	1.06	0.08	64	11.0	Present invention
22	365	360	363	5	480	483	480	3	34.5	35.0	34.1	0.9	0.97	0.98	1.07	0.10	60	11.7	Present invention
23	409	409	416	7	518	514	519	5	34.7	35.7	34.2	1.5	1.02	0.97	0.93	0.09	61	11.6	Present invention
24	405	410	415	10	511	512	512	1	35.8	36.1	36.2	0.4	0.89	1.11	0.94	0.19	60	11.6	Present invention
25	416	412	423	11	519	517	523	6	35.4	36.0	36.7	1.3	0.92	1.03	0.95	0.14	62	11.4	Present invention
26	417	414	424	10	521	515	524	9	33.4	34.9	34.7	1.5	1.00	1.15	0.98	0.17	63	11.1	Present invention
27	385	380	388	8	518	515	518	3	28.2	24.8	28.2	3.4	1.22	0.96	1.28	0.32	66	8.4	Comparative example
28	385	400	395	15	489	500	493	11	25.7	23.2	25.2	2.5	1.15	0.89	1.22	0.33	48	12.2	Comparative example
29	406	410	413	7	519	523	526	7	25.5	24.0	26.7	2.7	1.21	0.97	1.36	0.39	66	9.0	Comparative example
30	384	397	394	13	492	500	496	8	35.8	34.6	35.6	1.2	1.20	0.90	1.18	0.30	50	12.1	Comparative example
31	405	398	389	16	500	510	511	11	27.1	22.4	27.4	5.0	0.94	1.25	0.97	0.31	64	11.1	Comparative example
32	386	396	406	20	486	497	503	17	33.7	31.9	34.8	2.9	0.81	1.17	0.94	0.36	62	11.4	Comparative example
33	416	412	425	13	521	516	523	7	33.2	35.1	34.8	1.9	1.04	1.32	1.01	0.31	61	11.5	Comparative example
34	402	391	388	14	512	510	515	5	35.7	34.8	34.3	1.4	1.22	0.97	1.34	0.37	53	11.9	Comparative example
35	405	395	394	11	514	511	517	6	35.5	34.8	34.1	1.4	1.17	0.88	1.18	0.30	51	12.0	Comparative example
36	420	417	431	14	523	519	525	6	33.3	34.8	34.5	1.5	1.00	1.26	0.93	0.33	65	10.0	Comparative example
37	375	363	370	12	482	490	485	8	34.3	35.2	34.0	1.2	1.21	0.93	1.24	0.31	56	11.8	Comparative example
38	336	350	331	19	517	528	526	11	34.5	32.4	33.8	2.1	1.10	0.83	1.29	0.44	46	12.4	Comparative example

[0076]

As shown in Table 7, since the inventive steel sheets 20-26 have diameters and numbers of carbides within the range of the present invention, the HRc after quenching of these steel sheets is above 50 and the good hardenability is obtained. And the austenite grain size of these steel sheets is small, and therefore the excellent toughness is obtained. In addition, since the Δmax of yield strength and tensile strength is 15 MPa or lower, the Δmax of the total elongation is 1.5 % or lower, and the Δmax of r-value is less than 0.2, the planar anisotropy of tensile properties is very small.

[0077]

In contrast, the comparative steel sheets have a large Δmax of tensile properties, or poor hardenability or toughness. The steel sheet 30 of too high primary annealing temperature has a large Δmax of r-value of 0.26. The steel sheet 32 of too low cold reduction rate of 30 % has a large Δmax of yield strength of 20 MPa, a large Δmax of tensile strength of 17 MPa, and a large Δmax of r-value of 0.39. The steel sheet 35 of too high secondary annealing temperature has a low HRc of 51 due to the insufficient dissolution of carbides. The steel sheet 36 of too low secondary annealing temperature has poor toughness due to the coarse austenite grain caused by the large number of carbides having a diameter of 0.6 μm or less. The conventional steel sheet 38 has a large Δmax of r-value of 0.46.

[0078]

(Example 4)

This example relates to the method 2 for producing the high carbon steel sheet of the third invention.

By making a slab containing the chemical composition specified by S35C of JIS G 4051 (by wt%, C: 0.36 %, Si: 0.20 %, Mn: 0.75 %, P: 0.011 %, S: 0.002 % and Al: 0.020 %) through a continuous casting process, reheating to 1100 °C, hot rolling, coiling, primarily annealing, cold rolling, secondarily annealing, under the conditions shown in Table 8, and temper rolling at a reduction rate of 1.5 %, 26 steel sheets of 2.5 mm thickness were produced.

[0079]

Table 8

Steel sheet	Reheating of sheet bar (℃xsec)	Coiling temperature (℃)	Primary annealing (℃xhr)	Cold reduction rate (%)	Secondary annealing (℃xhr)	Secondary annealing range by the formula (1)	Number of carbides larger than 1.5 μm	Ratio of carbides smaller than 0.6 μm (%)	Remark
39	1050 x 15	580	640 x 40	70	680 x 40	632 - 680	55	86	Present invention
40	1100 x 3	530	640 x 20	60	680 x 40	632 - 680	52	87	Present invention
41	950 x 3	595	640 x 40	60	680 x 20	632 - 680	64	81	Present invention
42	1050 x 15	580	660 x 40	60	660 x 40	620 - 680	60	84	Present invention
43	1050 x 15	580	680 x 20	60	640 x 40	620 - 666	62	82	Present invention
44	1050 x 15	580	640 x 40	50	660 x 40	632 - 680	56	85	Present invention
45	1050 x 15	580	640 x 40	70	640 x 40	632 - 680	54	86	Present invention
46	-	580	640 x 40	70	680 x 40	632 - 680	56	85	Present invention
47	-	530	640 x 20	60	680 x 40	632 - 680	53	86	Present invention
48	-	595	640 x 40	60	680 x 20	632 - 680	64	81	Present invention
49	-	580	660 x 40	60	660 x 40	620 - 680	61	83	Present invention
50	-	580	680 x 20	60	640 x 40	620 - 666	63	82	Present invention
51	-	580	640 x 40	50	660 x 40	632 - 680	56	85	Present invention

Table 8 (continued)

Steel sheet	Reheating of sheet bar (℃xsec)	Coiling temperature (℃)	Primary annealing (℃xhr)	Cold reduction rate (%)	Secondary annealing (℃xhr)	Secondary annealing range by the formula (1)	Number of carbides larger than 1.5 μm	Ratio of carbides smaller than 0.6 μm (%)	Remark
52	-	580	640 x 40	70	640 x 40	632 - 680	55	85	Present invention
53	1050 x 15	510	640 x 20	60	680 x 40	632 - 680	30	92	Comparative example
54	1100 x 3	610	640 x 20	60	680 x 20	632 - 680	67	61	Comparative example
55	950 x 3	580	620 x 40	60	680 x 40	-	32	89	Comparative example
56	1050 x 15	580	720 x 40	60	680 x 40	-	68	65	Comparative example
57	1050 x 15	580	640 x 15	70	680 x 40	632 - 680	55	86	Comparative example
58	1050 x 15	580	640 x 40	30	680 x 40	632 - 680	58	84	Comparative example
59	1050 x 15	580	660 x 20	60	610 x 40	620 - 680	60	84	Comparative example
60	1050 x 15	580	640 x 20	60	700 x 40	632 - 680	66	74	Comparative example
61	1050 x 15	580	640 x 40	60	690 x 40	632 - 680	66	70	Comparative example
62	1050 x 15	580	690 x 40	60	615 x 40	620 – 658	33	88	Comparative example
63	1050 x 15	520	640 x 20	60	640 x 20	632 – 680	45	88	Comparative example
64	1050 x 15	620	-	50	690 x 40	-	33	87	Comparative example

[0080]

Carbide diameter, carbide dispersion, tensile properties, hardenability and austenite grain size were measured in the same way as shown in the Example 1,. The results are shown in Table 9. Herein, the steel sheet 64 is a conventional high carbon steel sheet.

[0081]

Table 9

Steel sheet	Mechanical properties before quenching																Hardness after quenching (HRc)	Austetine grain size (size No.)	Remark
	Yield strength (MPa)				Tensile strength (MPa)				Total elongation (%)				r-value						
	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δmax			
39	398	394	398	4	506	508	512	6	36.5	37.4	37.0	0.9	1.07	0.99	1.02	0.08	55	11.0	Present invention
40	410	407	410	3	514	512	516	4	36.8	37.7	36.8	0.9	1.04	1.01	1.11	0.10	56	10.9	Present invention
41	351	348	350	3	470	474	473	4	36.4	36.8	36.2	0.6	1.03	1.01	1.09	0.08	51	11.6	Present invention
42	395	398	400	5	508	506	509	3	36.8	37.5	37.3	0.7	1.09	0.99	1.02	0.10	53	11.4	Present invention
43	395	397	400	5	501	503	501	2	37.9	38.2	38.1	0.3	0.95	1.09	1.00	0.14	52	11.4	Present invention
44	401	399	404	5	509	510	512	3	37.7	37.9	38.5	0.8	0.94	1.07	1.04	0.13	53	11.3	Present invention
45	404	401	405	4	511	509	512	3	35.7	36.7	36.6	1.0	1.03	1.15	1.01	0.14	55	11.0	Present invention
46	397	394	402	8	506	508	513	7	36.2	37.4	37.1	1.2	1.14	0.99	1.00	0.15	54	11.1	Present invention
47	409	407	412	5	514	512	516	4	36.8	38.0	36.9	1.2	1.02	1.01	1.14	0.16	55	11.0	Present invention
48	351	348	351	3	470	474	469	5	36.4	36.8	36.2	0.6	1.01	0.98	1.13	0.15	51	11.6	Present invention
49	395	397	404	9	507	505	509	4	36.6	37.5	37.2	0.9	1.13	0.96	1.01	0.17	52	11.5	Present invention
50	392	396	400	8	502	505	501	4	37.2	38.2	38.0	1.0	0.95	1.14	1.00	0.19	51	11.5	Present invention
51	403	398	407	9	509	505	512	3	37.5	37.7	38.5	1.0	0.94	1.12	1.02	0.18	53	11.3	Present invention

Table 9 (continued)

Steel sheet	Mechanical properties before quenching																Hardness after quenching (HRc)	Austetine grain size (size No.)	Remark
	Yield strength (MPa)				Tensile strength (MPa)				Total elongation (%)				r-value						
	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δmax			
52	405	401	410	9	510	507	512	5	35.3	36.7	36.4	1.4	1.03	1.19	1.00	0.19	54	11.1	Present Invention
53	372	364	374	10	507	503	508	5	29.8	28.4	31.3	2.9	1.26	1.02	1.37	0.35	58	8.3	Comparative example
54	371	388	379	15	482	491	484	9	27.1	25.0	26.3	2.1	1.27	0.98	1.27	0.29	41	12.0	Comparative example
55	392	398	399	7	512	509	515	6	27.2	25.4	28.2	2.8	1.33	1.04	1.36	0.32	58	9.0	Comparative example
56	372	385	380	13	484	489	486	5	37.7	36.6	37.3	1.1	1.23	0.95	1.25	0.30	42	12.0	Comparative example
57	390	384	378	12	490	500	497	10	28.8	24.9	29.4	4.5	1.16	0.89	1.20	0.31	55	10.9	Comparative example
58	372	385	390	18	480	487	493	13	35.4	33.7	36.5	2.8	0.88	1.19	0.91	0.31	53	11.3	Comparative example
59	405	401	410	9	510	506	513	7	35.1	37.0	36.6	1.9	1.01	1.27	0.94	0.33	52	11.4	Comparative example
60	383	386	376	10	504	501	506	5	37.5	36.9	36.4	1.1	1.18	0.94	1.29	0.35	45	11.7	Comparative example
61	387	389	378	11	503	501	507	6	37.3	36.6	36.0	1.3	1.16	1.00	1.45	0.45	44	11.9	Comparative example
62	410	404	417	13	513	507	515	8	35.3	36.7	36.1	1.4	0.87	1.17	0.88	0.29	56	9.9	Comparative example
63	411	406	415	9	515	511	515	8	35.1	36.5	36.0	1.4	1.02	1.32	1.00	0.32	57	9.4	Comparative example
64	323	335	322	13	510	519	513	9	36.1	34.1	35.5	2.0	1.10	0.93	1.35	0.40	43	12.0	Comparative example

Table 9 (continued)

Steel sheet	Integrated reflective intensity (222)				Remark
	Surface	1/4 thickness	1/2 thickness	Δmax	
39	2.80	2.79	2.90	0.11	Present invention
40	2.85	2.92	3.00	0.15	Present invention
41	2.87	2.93	3.00	0.13	Present invention
42	2.72	2.80	2.84	0.12	Present invention
43	2.54	2.60	2.66	0.12	Present invention
44	2.85	2.93	2.99	0.14	Present invention
45	2.88	3.01	2.95	0.13	Present invention
46	2.75	2.90	3.03	0.28	Present invention
47	2.77	3.06	2.98	0.29	Present invention
48	2.79	2.74	3.02	0.28	Present invention
49	2.65	2.77	2.90	0.25	Present invention
50	2.48	2.58	2.75	0.27	Present invention
51	2.80	3.02	2.97	0.22	Present invention
52	2.83	2.80	3.04	0.24	Present invention
53	2.81	2.88	2.96	0.15	Comparative example
54	2.84	2.87	2.98	0.14	Comparative example
55	2.90	3.04	2.99	0.14	Comparative example
56	2.20	2.28	2.32	0.12	Comparative example
57	2.82	2.93	2.91	0.11	Comparative example
58	2.83	2.90	2.98	0.15	Comparative example
59	2.73	2.79	2.86	0.13	Comparative example
60	2.85	2.92	3.00	0.15	Comparative example
61	2.82	2.96	2.93	0.14	Comparative example
62	2.38	2.42	2.53	0.15	Comparative example
63	2.83	2.88	2.96	0.13	Comparative example
64	2.33	2.39	2.48	0.15	Comparative example

[0082]

As shown in Table 9, since the inventive steel sheets 39-52 have diameters and numbers of carbides within the range of the present invention, the HRc after quenching of these steel sheets is above 50 and the good hardenability is obtained. And the austenite grain size of these steel sheets is small, and therefore the excellent toughness is obtained. In addition, since the Δ max of yield strength and tensile strength is 10 MPa or lower, the Δmax of the total elongation is 1.5 % or lower, and the Δ max of r-value is less than 0.2, the planar anisotropy of tensile properties is very small. The heating after rough rolling is effective not only for reducing the planar anisotropy of tensile properties but also for making the structure uniform in a thickness direction.

[0083]

In contrast, the comparative steel sheets have a large Δ max of tensile properties, or poor hardenability or toughness. The steel sheet 56 of too high primary annealing temperature has a large Δmax of r-value of 0.30. The steel sheet 58 of too low cold reduction rate of 30 % has a large Δmax of yield strength of 18 MPa, a large Δmax of tensile strength of 13 MPa, and a large Δmax of r-value of 0.38. The steel sheet 61 of too high secondary annealing temperature has a low HRc of 44 due to the insufficient dissolution of carbides. The steel sheet 62 of too low secondary annealing temperature has poor toughness due to the coarse austenite grain caused by the large number of carbides having a diameter of 0.6 μm or less. The conventional steel sheet 64

has a large Δmax of r-value of 0.42.

[0084]

(Example 5)

This example relates to the method 2 for producing the high carbon steel sheet of the third invention, too.

By making a slab containing the chemical composition specified by S65C-CSP of JIS G 4802 (by wt%, C: 0.65 %, Si: 0.19 %, Mn: 0.73 %, P: 0.011 %, S: 0.002 % and Al: 0.020 %) through a continuous casting process, reheating to 1100 °C, hot rolling, coiling, primarily annealing, cold rolling, secondarily annealing, under the conditions shown in Table 10, and temper rolling at a reduction rate of 1.5 %, 26 steel sheets of 2.5 mm thickness were produced.

[0085]

Table 10

Steel sheet	Reheating of sheet bar (℃xsec)	Coiling temperature (℃)	Primary annealing (℃xhr)	Cold reduction rate (%)	Secondary annealing (℃xhr)	Secondary annealing range by the formula (1)	Number of carbides larger than 1.5 μm	Ratio of carbides smaller than 0.6 μm (%)	Remark
65	1050 x 15	560	640 x 40	70	680 x 40	632 – 680	85	87	Present invention
66	1100 x 3	530	640 x 20	60	680 x 40	632 – 680	82	88	Present invention
67	950 x 3	595	640 x 40	60	680 x 20	632 – 680	94	82	Present invention
68	1050 x 15	560	660 x 40	60	660 x 40	620 – 680	89	84	Present invention
69	1050 x 15	560	680 x 20	60	640 x 40	620 – 666	91	83	Present invention
70	1050 x 15	560	640 x 40	50	660 x 40	632 – 680	87	85	Present invention
71	1050 x 15	560	640 x 40	70	640 x 40	632 – 680	83	86	Present invention
72	-	560	640 x 40	70	680 x 40	632 – 680	86	86	Present invention
73	-	530	640 x 20	60	680 x 40	632 – 680	83	87	Present invention
74	-	595	640 x 40	60	680 x 20	632 – 680	94	82	Present invention
75	-	560	660 x 40	60	660 x 40	620 – 680	90	83	Present invention
76	-	560	680 x 20	60	640 x 40	620 – 666	92	83	Present invention
77	-	560	640 x 40	50	660 x 40	632 – 680	87	85	Present invention

Table 10 (continued)

Steel sheet	Reheating of sheet bar (°C×sec)	Coiling temperature (°C)	Primary annealing (°C×hr)	Cold reduction rate (%)	Secondary annealing (°C×hr)	Secondary annealing range by the formula (1)	Number of carbides larger than 1.5 μm	Ratio of carbides smaller than 0.6 μm (%)	Remark
78	-	560	640 x 40	70	640 x 40	632 – 680	84	85	Present invention
79	1050 x 15	510	640 x 20	60	680 x 40	632 – 680	44	93	Comparative example
80	1100 x 3	610	640 x 20	60	680 x 20	632 – 680	100	62	Comparative example
81	950 x 3	560	620 x 40	60	680 x 40	-	47	90	Comparative example
82	1050 x 15	560	720 x 40	60	680 x 40	-	100	64	Comparative example
83	1050 x 15	560	640 x 15	70	680 x 40	632 – 680	84	87	Comparative example
84	1050 x 15	560	640 x 40	30	680 x 40	632 – 680	88	85	Comparative example
85	1050 x 15	560	660 x 20	60	610 x 40	620 – 680	89	84	Comparative example
86	1050 x 15	560	640 x 20	60	700 x 40	632 – 680	98	73	Comparative example
87	1050 x 15	560	640 x 40	60	690 x 40	632 – 680	98	70	Comparative example
88	1050 x 15	560	690 x 40	60	615 x 40	620 – 680	49	89	Comparative example
89	1050 x 15	600	690 x 20	50	650 x 40	632 – 680	96	77	Comparative example
90	1050 x 15	610	-	50	690 x 40	-	99	71	Comparative example

[0086]

Carbide diameter, carbide dispersion, tensile properties, hardenability and austenite grain size were measured in the same way as shown in the Example 1,. The results are shown in Table 11. Herein, the steel sheet 90 is a conventional high carbon steel sheet.

[0087]

Table 11

Steel sheet	Mechanical properties before quenching																Hardness after quenching (HRc)	Austetine Grain size (size No.)	Remark
	Yield strength (MPa)				Tensile strength (MPa)				Total elongation (%)				r-value						
	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δmax			
65	412	406	412	6	515	518	521	6	34.7	35.7	35.2	1.0	1.04	0.96	0.98	0.08	64	11.1	Present invention
66	422	419	424	5	523	521	526	5	35.1	36.0	35.1	0.9	0.98	1.02	1.06	0.08	64	11.0	Present invention
67	364	360	363	4	480	483	481	3	34.5	35.0	34.3	0.7	0.97	0.99	1.07	0.10	60	11.7	Present invention
68	409	409	415	6	517	514	519	5	34.7	35.7	34.7	1.0	1.02	0.96	0.93	0.09	62	11.5	Present invention
69	405	410	412	7	511	511	512	1	35.8	36.0	36.2	0.4	0.92	1.06	0.94	0.14	61	11.5	Present invention
70	416	412	421	9	520	517	523	6	35.9	36.0	36.7	0.8	0.89	1.03	0.96	0.14	62	11.4	Present invention
71	417	414	421	7	521	515	521	6	33.9	34.9	34.7	1.0	1.00	1.12	0.98	0.14	63	11.1	Present invention
72	411	406	413	7	515	519	523	8	34.2	35.7	35.3	1.5	1.08	0.93	0.97	0.15	63	11.2	Present invention
73	423	419	427	8	523	521	526	5	35.3	36.0	34.6	1.4	0.94	1.00	1.10	0.16	63	11.1	Present invention
74	365	360	362	5	479	483	480	4	34.6	35.0	34.1	0.9	0.95	0.98	1.12	0.17	60	11.7	Present invention
75	410	409	416	7	517	514	519	5	34.6	35.7	34.2	1.5	1.07	0.97	0.91	0.16	61	11.6	Present invention
76	405	408	415	10	511	512	514	3	35.4	36.1	36.6	1.2	0.92	1.11	0.95	0.19	60	11.6	Present invention
77	417	412	423	11	518	517	523	6	35.4	36.1	36.7	1.3	0.89	1.07	0.95	0.18	62	11.4	Present invention

Table 11 (continued)

Steel sheet	Mechanical properties before quenching																Hardness after quenching (HRc)	Austetine grain size (size No.)	Remark
	Yield strength (MPa)				Tensile strength (MPa)				Total elongation (%)				r-value						
	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δmax			
78	418	414	424	10	520	515	524	9	33.4	34.9	34.5	1.5	1.00	1.17	0.98	0.19	62	11.2	Present invention
79	385	380	390	10	518	515	520	5	28.0	24.8	28.2	3.4	1.18	0.92	1.25	0.33	66	8.4	Comparative example
80	385	400	394	15	489	500	494	11	25.7	23.2	25.0	2.5	1.12	0.88	1.22	0.34	49	12.2	Comparative example
81	406	410	415	9	519	522	526	7	25.3	24.0	26.7	2.7	1.18	1.01	1.42	0.41	66	9.1	Comparative example
82	384	397	392	13	492	500	497	8	35.8	34.3	35.6	1.5	1.18	0.93	1.32	0.39	50	12.1	Comparative example
83	405	397	389	16	500	509	511	11	27.0	22.4	27.4	5.0	1.24	0.90	1.27	0.37	63	11.1	Comparative example
84	386	398	406	20	486	496	503	17	33.4	31.9	34.8	2.9	0.81	1.16	0.93	0.35	62	11.4	Comparative example
85	418	412	425	13	521	516	524	8	33.2	35.1	34.5	1.9	1.02	1.23	0.86	0.37	61	11.5	Comparative example
86	402	393	388	14	512	509	515	6	35.7	34.9	34.3	1.4	1.24	0.95	1.25	0.30	53	11.8	Comparative example
87	408	395	394	12	514	510	517	7	35.5	34.7	34.1	1.4	1.11	0.86	1.19	0.33	52	12.0	Comparative example
88	421	417	431	14	523	518	525	7	33.3	34.8	34.3	1.5	1.00	1.26	0.92	0.34	65	10.0	Comparative example
89	375	363	389	12	482	490	486	8	34.3	35.4	34.0	1.4	1.17	0.99	1.40	0.41	56	11.8	Comparative example
90	338	350	331	19	517	528	524	11	34.5	32.4	33.6	2.1	1.13	0.83	1.29	0.42	54	11.9	Comparative example

Table 11 (continued)

Steel sheet	Integrated reflective intensity (222)				Remark
	Surface	1/4 thickness	1/2 thickness	Δ max	
65	2.87	2.82	2.97	0.15	Present invention
66	2.83	2.86	2.94	0.11	Present invention
67	2.85	2.90	2.97	0.12	Present invention
68	2.75	2.81	2.86	0.11	Present invention
69	2.58	2.64	2.71	0.13	Present invention
70	2.84	2.91	2.96	0.12	Present invention
71	2.85	2.99	2.95	0.14	Present invention
72	2.73	2.85	3.02	0.29	Present invention
73	2.76	3.03	2.97	0.27	Present invention
74	2.78	2.92	3.04	0.26	Present invention
75	2.69	2.82	2.96	0.27	Present invention
76	2.50	2.64	2.75	0.25	Present invention
77	2.81	3.03	2.99	0.22	Present invention
78	2.79	2.87	3.03	0.24	Present invention
79	2.83	2.87	2.96	0.13	Comparative example
80	2.84	2.88	2.99	0.15	Comparative example
81	2.92	3.03	2.95	0.11	Comparative example
82	2.22	2.26	2.34	0.12	Comparative example
83	2.85	2.97	2.92	0.12	Comparative example
84	2.88	2.94	3.02	0.14	Comparative example
85	2.73	2.75	2.87	0.14	Comparative example
86	2.84	2.87	2.99	0.15	Comparative example
87	2.86	3.01	2.92	0.15	Comparative example
88	2.40	2.42	2.54	0.14	Comparative example
89	2.89	2.98	3.04	0.15	Comparative example
90	2.37	2.40	2.50	0.13	Comparative example

[0088]

As shown in Table 11, since the inventive steel sheets 65-78 have diameters and numbers of carbides within the range of the present invention, the HRc after quenching of these steel sheets is above 50 and the good hardenability is obtained. And the austenite grain size of these steel sheets is small, and therefore the excellent toughness is obtained. In addition, since the Δmax of yield strength and tensile strength is 15 MPa or lower, the Δmax of the total elongation is 1.5 % or lower, and the Δmax of r-value is less than 0.2, the planar anisotropy of tensile properties is very small. The heating after rough rolling is effective not only for reducing the planar anisotropy of tensile properties but also for making the structure uniform in a thickness direction.

[0089]

In contrast, the comparative steel sheets have a large Δmax of tensile properties, or poor hardenability or toughness. The steel sheet 82 of too high primary annealing temperature has a large Δmax of r-value of 0.27. The steel sheet 84 of too low cold reduction rate of 30 % has a large Δmax of yield strength of 20 MPa, a large Δmax of tensile strength of 17 MPa, and a large Δmax of r-value of 0.39. The steel sheet 87 of too high secondary annealing temperature has a low HRc of 52 due to the insufficient dissolution of carbides. The steel sheet 88 of too low secondary annealing temperature has poor toughness due to the coarse austenite grain caused by the large number of carbides having a diameter of 0.6 μm or less. The conventional steel sheet 90

has a large Δmax of r-value of 0.46.

[0090]

[Advantages]

As explained above, the present invention enables to provide a high carbon steel sheet having excellent hardenability and toughness, and low planar anisotropy of tensile properties affecting workability. As a result, the high carbon steel sheet of the present invention is applicable to parts as gears which need a high dimensional precision. Since the parts as gears can be formed and subjected to quenching and tempering, their production cost becomes much lower as compared with parts as gears produced conventionally by casting or forging.

[Brief Description of the Drawings]

Fig. 1 shows the effect of the diameter of carbide before quenching on the hardness when a steel sheet of S35C was heated at 820 ℃ for 10 sec and then quenched into oil;

Fig. 2 shows the effect of the number of carbides having a diameter of 1.5 μm or larger on the austenite grain size when a steel sheet of S35C was heated at 820 ℃ for 10 sec and then quenched into oil;

Fig. 3 shows the effect of primary annealing temperature and secondary annealing temperature on the Δmax of r-value and the carbide dispersion in the method 1 for producing the high carbon steel sheet of the third invention; and

Fig. 4 shows the effect of primary annealing temperature and secondary annealing temperature on the Δmax of r-value and the carbide dispersion in the method 2 for producing the high carbon steel sheet of the third invention.

[Name of the Document] ABSTRACT

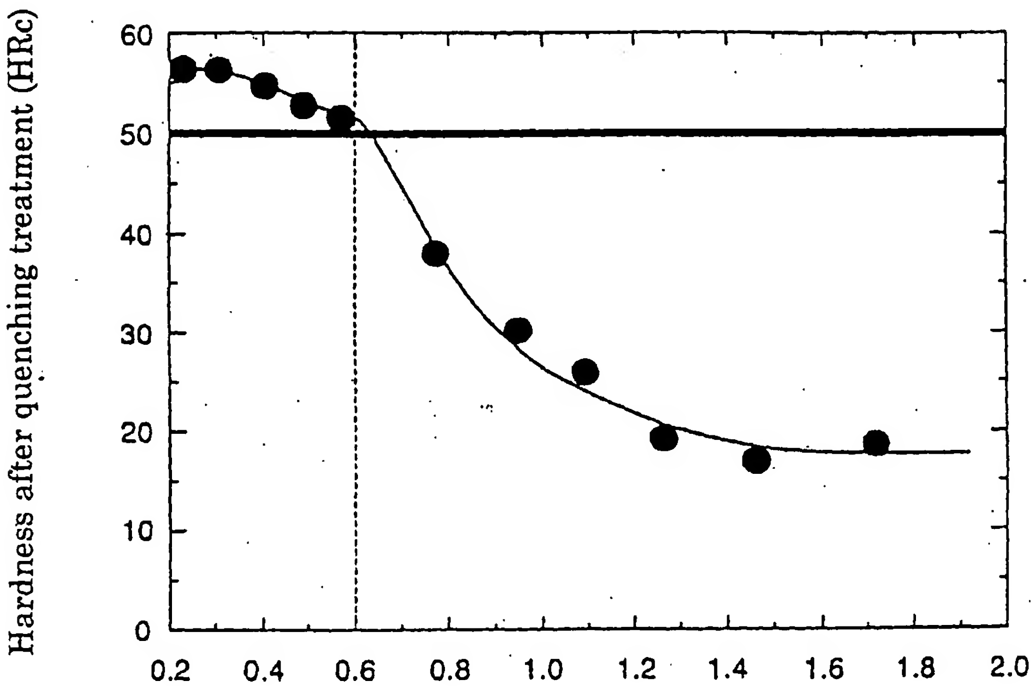
[Abstract]

[Object] To provide a high carbon steel sheet having excellent hardenability and toughness, and low planar anisotropy of tensile properties affecting workability, and a method of producing the same.

[Means for Solution] A high carbon steel sheet having chemical composition specified by JIS G 4051 (Carbon steels for machine structural use), JIS G 4401 (Carbon tool steels) or JIS G 4802 (Cold-rolled steel strips for springs), wherein more than 50 carbides having a diameter of 1.5 μm or larger exist in 2500 μm^2, the ratio of number of carbides having a diameter of 0.6 μm or less with respect to all the carbides is 80 % or more, and the Δr is more than -0.15 to less than 0.15, herein $\Delta r = (r0 + r90 - 2 \times r45)/4$, and r0, r45, and r90 shows a r-value of the directions of 0°(L), 45°(S) and 90°(C) with respect to the rolling direction respectively.

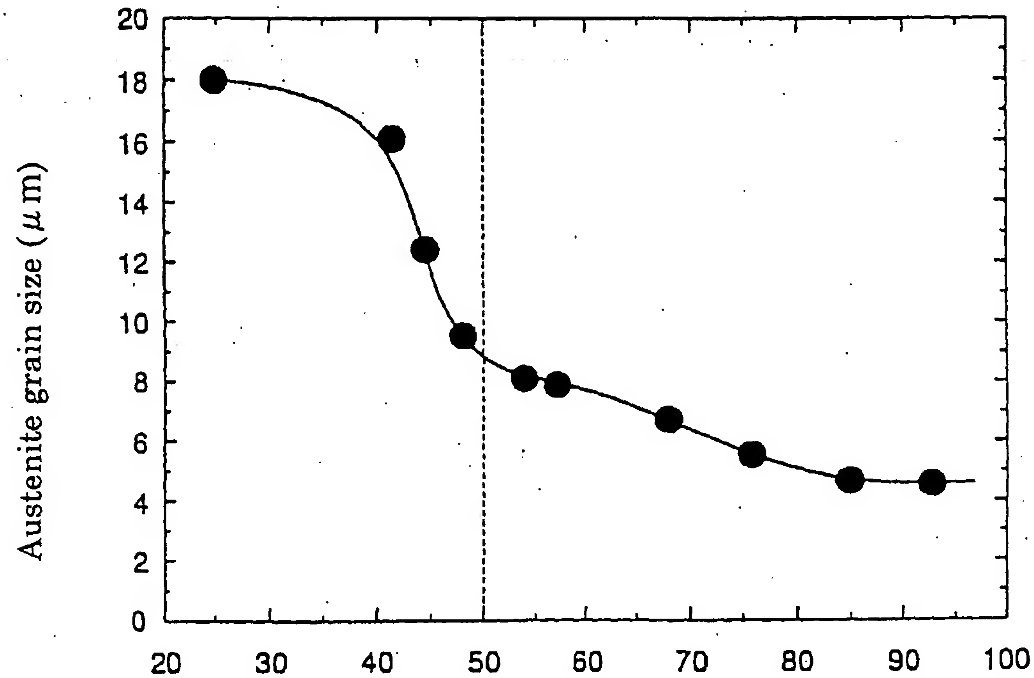
[Selected Drawing] None

FIG. 1



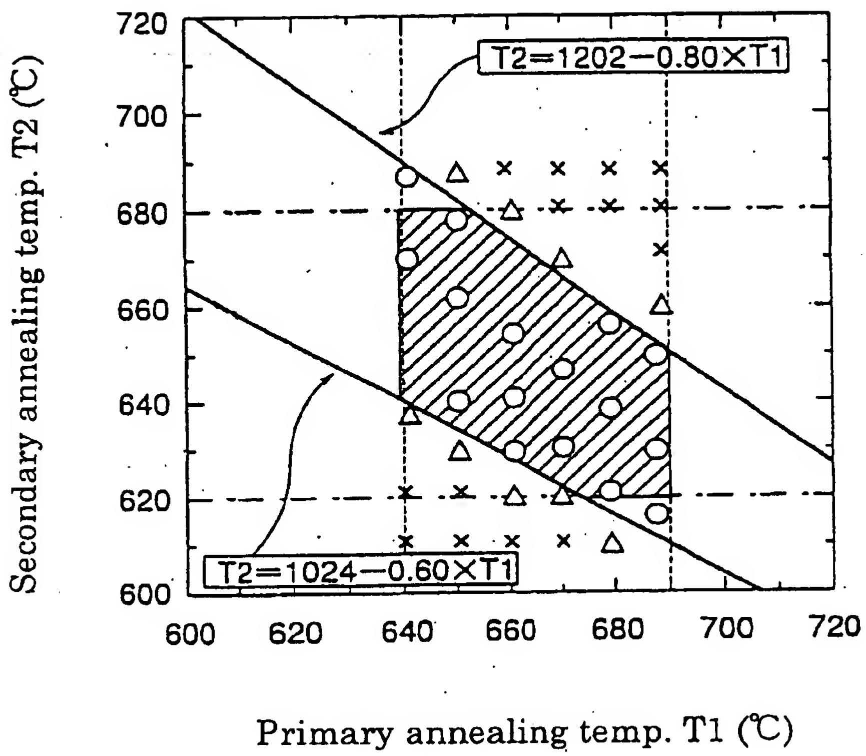
Maximum diameter Dmax (μm) of carbide when 80 % or more is the ratio of number of carbides having diameter $\leqq$ Dmax with respect to all the carbides

FIG. 2



Number of carbides having a diameter of 1.5 µm or larger which exist in 2500 µm² of observation field area of electron microscope

FIG. 3

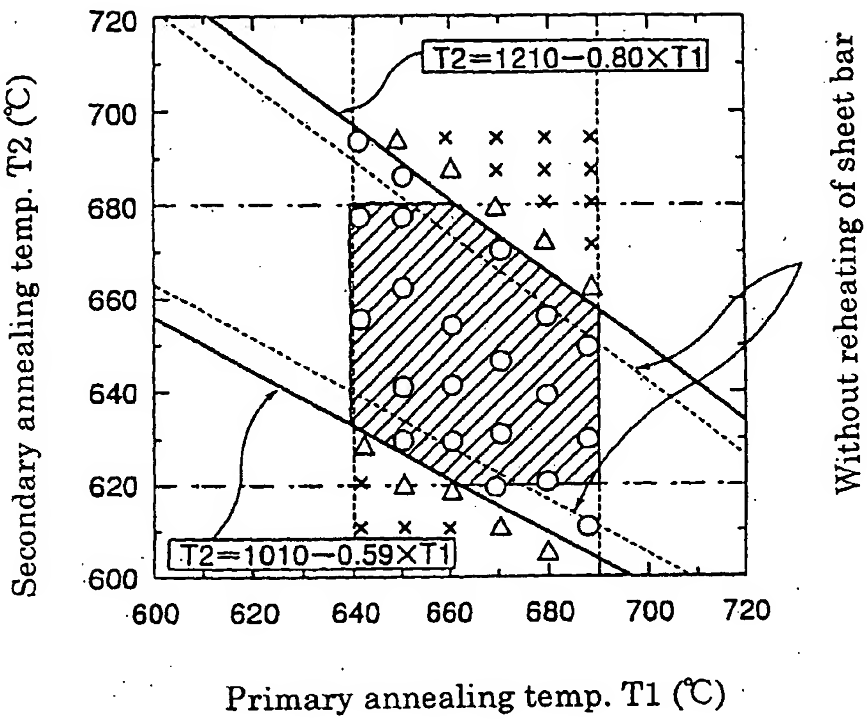


○ : Δmax < 0.2

△ : 0.2 ≦ Δmax < 0.4

× : 0.4 ≦ Δmax

FIG. 4



○ : Δmax < 0.15

△ : 0.15 ≦ Δmax < 0.35

× : 0.35 ≦ Δmax